CE 400 / CE 500

Process Safety Management

Lecture 34 Relief Devices III

Instructor: David Courtemanche

University at Buffalo
Department of Chemical and Biological Engineering
School of Engineering and Applied Sciences

Spring Loaded Relief Valve – Liquid Service

- Design starts with identifying the scenario that you need to protect against
  - Typical scenario is a positive displacement pump that has a blocked discharge line
  - Positive displacement pumps will build up enough pressure to either damage the piping or the pump housing
  - For flammable service it is a RAGAGEP* requirement to provide pressure relief

* Recognized And Generally Accepted Good Engineering Practice

Scenario

- Assume worst case conditions
  - Pump is running at full speed and therefore full volumetric capacity
  - Set pressure must not exceed the pressure rating of the equipment being protected
- Back pressure is provided by the resistance to flow in the discharge piping of the relief circuit
- Calculate Reynold’s number based on maximum capacity

Pump Capacity	100 gpm
Set Pressure	50 psig
Overpressure	5 psig
Backpressure	5 psig
Valve type	Conventional
$\frac{\rho}{\rho_{ref}}$	1.0

You may assume a Reynold’s number of 10,000

Relief Devices

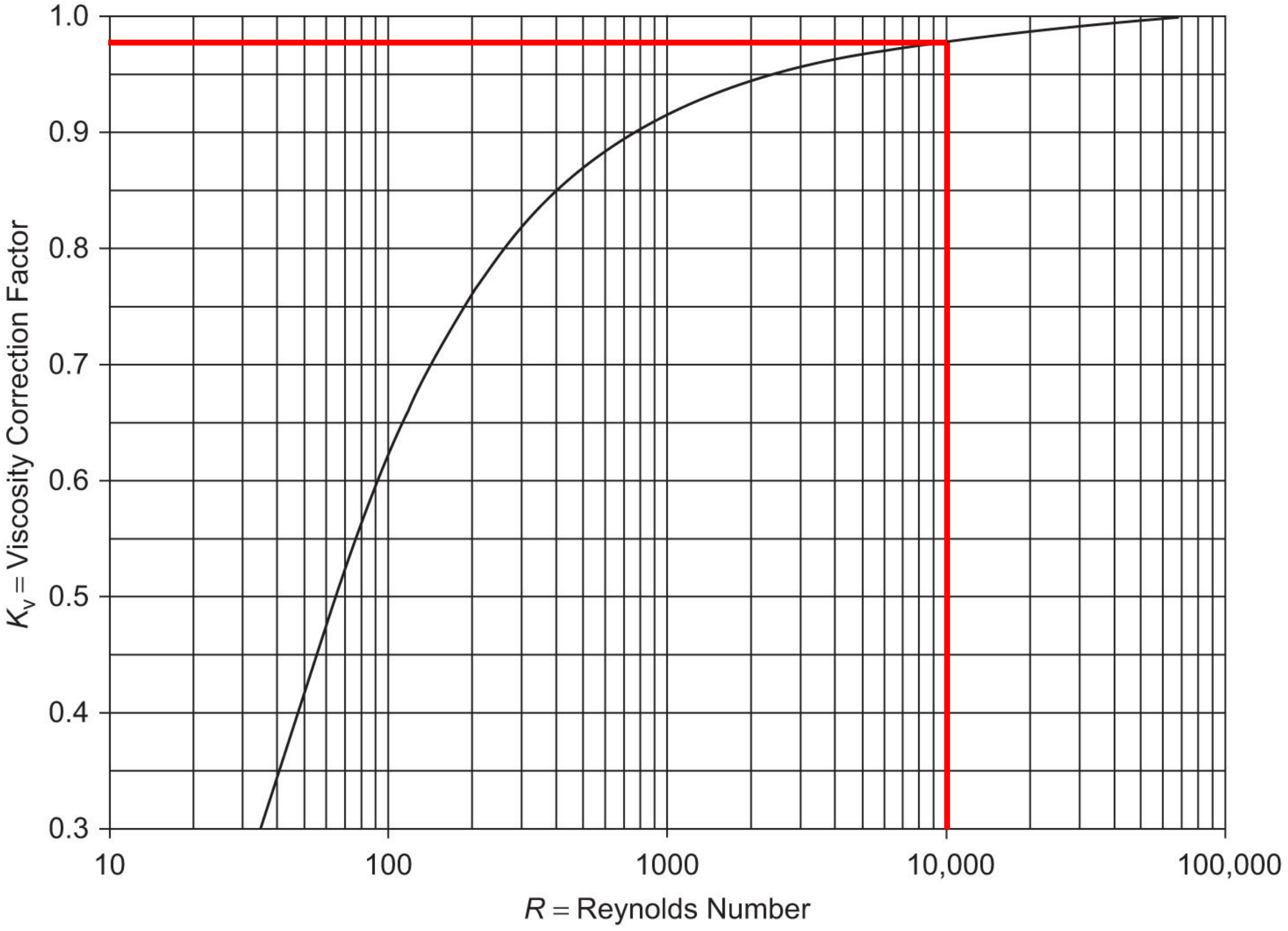

Figure 10-3 Viscosity correction factor Kv for conventional and balanced bellows reliefs in liquid service. This is drawn using the equation $\ln K_v = 0.08547 - 0.9541/\ln R - 35.571/R$ using data from API RP 520, Recommended Practice for the Sizing, Selection, and Installation of Pressure-Relieving Systems in Refineries, 9th ed. (Washington, DC: American Petroleum Institute, 2014).

Relief Devices

Equation 10-4 applies for liquid service

$$A = \left[\frac{in^2(psi)^{1/2}}{38.0\ gpm}\right]\frac{Q_V}{C_0 K_b K_c K_V}\sqrt{\frac{\left(\rho/\rho_{ref}\right)}{P_1 - P_2}}$$

$Q_V = 100\ gpm$
$C_0 = 0.65\ for\ preliminary\ sizing\ for\ a\ spring - relief\ valve$
$K_b = 1.0\ for\ a\ conventional\ spring\ relief$
$K_c = 1.0\ since\ there\ is\ no\ rupture\ disc\ installed\ upstream$
$K_V = 0.97\ from\ Figure\ 10 - 3\ with\ Reynolds\ number\ 10,000$
Note $K_P = 1.0\ for\ a\ certified\ device$

Then
$P_1 = 50\ psig + 5\ psig = 55\ psig$ since this is the set pressure + the overpressure
$P_2 = 5\ psig$ since this is the back pressure

Relief Devices

Substituting in equation 10-4:

$$A = \left[\frac{in^2 (psi)^{1/2}}{38.0\ gpm}\right] \frac{100\ gpm}{0.65 * 1.0 * 1.0 * 0.97} \sqrt{\frac{1.0}{55\ psig - 5\ psig}} = 0.591\ in^2$$

$$d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 * 0.591\ in^2}{\pi}} = 0.87\ inch\ diameter$$

Fire Exposure

A horizontal vessel, 3 m long and 1 m in diameter, contains water. What relief size is required to protect the vessel from fire exposure?

Assume the following: vapor relief only, MAWP of 14 Barg, the relief device is a conventional capacity certified spring-operated relief.

Properties of steam at 15.013 Bar absolute:

$$T = 198\ C = 471\ K$$

$$v_f = 0.00115\ {m^3}/{kg}$$

$$h_{fg} = 1946\ kJ/kg$$

Relief Devices

Need to calculate the total Surface area of the vessel

$$2\pi r^2 + \pi D h = 2\pi(0.5\ m)^2 + \pi * 1\ m * 3\ m = 11.0\ m^2 = 118.4\ ft^2$$

From equation 10-30 for a horizontal tank we will use 75% of this area in the following equation:

$$A = 0.75 * 118.4\ ft^2 = 88.8\ ft^2$$

$Q = 20{,}000\ A$ for 20 < A < 200 where $Q\ is\ in\ {}^{BTU}/_{hr}$ and $A\ is\ in\ ft^2$

$$Q = 20{,}000 * 88.8\ ft^2 = 1.78 * 10^6 \frac{BTU}{hr} * \frac{1.055\ kJ}{1\ BTU} * \frac{hr}{3600\ s} = 520.5\ \frac{kJ}{s}$$

Relief Devices

Assuming no overpressure the contents of the vessel will be at 15.013 bar absolute when venting, so we can use data given in problem statement.

If we assume some overpressure (which we normally will do) we would need steam properties at that higher pressure.

For vapor relief, the mass discharge rate through the relief is:

$$Q_m = \frac{Q}{h_{fg}}$$

$$Q_m = \frac{Q}{h_{fg}} = \frac{520.5\ \frac{kJ}{s}}{1946\ kJ/kg} = 0.267\ \frac{kg}{s}$$

Relief Devices

Use Equation 10-12 to size the relief

$$A = \frac{Q_m}{\chi C_0 K_b K_c P}\sqrt{\frac{Tz}{M}}$$

Where

$A\ is\ the\ area\ of\ the\ relief\ vent, m^2$

$Q_m\ is\ the\ discharge\ mass\ flow, kg/s$

$C_0\ is\ effective\ discharge\ coefficient, unitless$

$K_b\ is\ the\ backpressure\ coefficient, unitless$

$K_c\ is\ the\ combination\ correction\ factor, unitless$

$P\ is\ the\ upstream\ relieving\ pressure\ , equal\ to\ the\ set\ pressure\ plus\ the\ allowable\ overpressure,$ bar absolute

$T\ is\ the\ absolute\ temperature, K$

$z\ is\ the\ compressibility\ factor, unitless$

$M\ is\ the\ average\ molecular\ weight\ of\ the\ discharge\ material, kg/mol$

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$$\chi = \left[3.468 * \ 10^4 \frac{(mol\ kg\ K)^2}{bar\ s\ m^2}\right]\sqrt{\gamma\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}$$

For water: $M = 18\ g/mol, z = 1.0, \gamma = 1.32\ for\ a\ triatomic\ gas$

$$\chi = \left[3.468 * \ 10^4 \frac{(mol\ kg\ K)^2}{bar\ s\ m^2}\right]\sqrt{1.32\left(\frac{2}{2.32}\right)^{(2.32)/(0.32)}} = 2.33 * \ 10^4$$

From guidelines

$C_0 = 0.975$ for preliminary sizing

$K_b = 1.0\ for\ convential\ relief\ device$

$K_c = 1.0\ since\ there\ is\ no\ rupture\ disc$

Relief Devices

Substituting into equation 10-12

$$A = \frac{Q_m}{\chi C_0 K_b K_c P}\sqrt{\frac{Tz}{M}} = \frac{0.267\ \frac{kg}{s}}{2.33 *\ 10^4 * 0.975 * 1.0 * 1.0 * 15.013\ bar\ abs}\sqrt{\frac{471\ K * 1.0}{0.018\ kg/mol}} = 1.27 *\ 10^{-4}\ m^2$$

The relief diameter is:

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 *\ 1.27 *\ 10^{-4}\ m^2}{\pi}} = 0.0127 *\ m = 1.27\ cm = 0.5"$$

Vapor Vent with Rupture Disc

- Calculate required flow as before starting on slide 7
- Select a vent diameter, length, and routing
- Calculate the flow rate through the vent assuming that internal pressure is equal to the rated pressure
- The rupture disc manufacturer will supply a factor that can be used in the calculation of flow rate
    - It will factor in the same way a fitting, such as an elbow, does
- Compare the rated flow to the required flow
- If the rated flow is greater than the required flow by a set safety factor then you are good